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OPERATING EXPERIENCE WITH IBR REACTOR, ITS USE FOR NEUTRON INVESTIGATIONS AND ITS CHARACTERISTICS ON NEUTRON INJECTION FROM A MICROTRON

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1. Introduction

A considerable part of physical investigations carried out on nuclear reactors are connected with the isolation of monoenergetic neutron beams or with measuring neutron spectra. In such experiments, conventional stationary reactors are actually used quite irrationally. Thus, for example, when applying the time-of-flight method the neutron beam is open maximum 1 per cent of the time whereas 99 per cent of the time the reactor serves as the source of interfering background. From the point of view of neutron-spectrometric investigations, it is much more rational to use pulsed conditions of reactor operation. These considerations stimulated the setting up of a fast-neutron pulsed reactor (IBR) at the Joint Nuclear Research Institute in Dubna.

The physical startup of the reactor was accomplished in June 1960. At the end of 1960 the reactor was brought into normal operation and since then has been used for time-of-flight investigations. The principal lines of the investigation are: (1) study of liquids and solids with the aid of neutron scattering, and (2) neutron spectrometry, i.e. determination of neutron cross-sections and study of the excited states of atomic nuclei.

The IBR reactor operates under conditions of periodic pulses with a half-width of 36-40 μsec and a repetition rate which may be varied from 3.3 to 83 imp/sec. The average thermal power of the reactor is maintained constant. Initially it was 1 kW. In 1964

the average power was increased to 3 kW. At such an average power and a repetition rate of 3.3 imp/sec. the maximum instantaneous power of the reactor is about 23 MW. In the intervals between the pulses the reactor power does not exceed 100 W, and this ensures a low fast-neutron background. The small size of the IBR core allows better utilization of neutrons emitted by the reactor. Due to these circumstances, IBR makes possible time-of-flight investigations which would require a stationary reactor with a power running into tens of MW. At the same time, IBR possesses a number of operational advantages characteristic of zero-power reactors. Indeed, such operational problem as the cooling of the core, the activation of the structural elements, the replacement of fissionable meterials, radiation safety and some others, depend on the average power of the reactor which is low in our case.

The theory of IBR operation is presented in Ref. 1, and its design and physical startup are described in Ref.2. This paper will only make a brief mention of these problems for consistency sake. The main objective of the paper is to set out the results of the reactor operation and its use for research purposes. We shall also discuss certain lines of investigation for which the reactor is to be used in future work.

2. Description of the Unit

The general view of the reactor is given in Fig.1. The periodic pulsed condition of reactor operation is achieved by placing part of the fissionable material carrying a reactivity of about 7.5 per cent, near the periphery of a steel disc, 1,100 mm in diameter which rotates at a speed of 5,000 rpm. This mobile part of the core is manufactured from uranium-235. It represents a disc, 100 mm in diameter and 28 mm thick encased in a hermetic can of stainless steel and pressed, with a negative allowance, into the appropriate opening in the disc. The center of the uranium insert is spaced 440 mm from the rotation axis of the disc.

The stationary part of the core consists of plutonium rods canned in stainless steel jackets. The mobile uranium insert moves in a recess between the two halves of the core. The dimensions of the stationary core together with the reflectors (tungsten, cupronickel) are approximately 300 mm x 200 mm x 200 mm.

To provide for the variation in the pulse repetition rate without changing the duration of the burst, use is made of an auxiliary fissionable insert pressed into a small disc and moving at the core boundary. The rotation speed of the small disc may be changed with the aid of a special gear box. The reactor goes supercritical, and power pulses develop when the main and auxiliary mobile inserts are simultaneously aligned with the fixed

part of the core. The reactor is controlled by shifting a plate with a small pressed-in insert of uranium-235 (coarse regulator) and two cupronickel rods which form part of the reflector (manual and automatic regulators). The safety elements are two plutonium rods which may be ejected from the core in less than 0.1 sec.

In Fig.1. the core is covered with a lead radiation shield, 10 cm thick. The shield is mounted on a remotely controlled truck which simultaneously serves for mounting, near the core, of hydrogen-containing plates for slowing down of the fast neutrons emitted by the reactor. The reactor is cooled forcibly by air. The reactor is sited in the centre of a hall 10 x 10 m^2 square, whose concrete walls and ceiling are 2 m thick and serve as biological shielding. To extract neuton beams, the shield is provided with 7 horizontal channels (Fig.2). 5 beams are brought out into the experimental hall and are used for work with flight pathes of up to 17 m. The remaining two beams serve for investigations with flight pathes of up to 100 and 1,000 m, respectively; they are encased in evacuated steel tubes-neutron guides, 400—800 mm in diameter. Some data on the intensity of the IBR neutron beams are listed in Table 1 (see also Ref.4).

Fig. 2 depicts the arrangement of various units used in investigations which will be discussed later in this paper. Pulses from detectors located at a number of points arrive, via cables, at the measuring centre (600 m from the reactor) where multichannel analyzers are concentrated (Fig.3). The time analyzers used at present have 256, 1,024 (2 ea) and 2,048 (3 ea) channels, respectively, and there is also a multidimensional (pulse height-time) analyzer with a magnetic tape memory containing up to 2^{20} channels /3/. From the analyzers, the data are delivered to fast-acting figure-printing typewriters, a puncher with a paper tape and, via a cable, directly to an electronic computer. The reactor is controlled from a separate building situated near a thousand-metre neutron guide at a distance of 250 m from the reactor.

3. Power Monitoring and Reactor Control

Continuous monitoring of reactor power at startup and during operation is effected by using indications of several ionization chambers and proportional counters which register fast neutrons. The same detectors are used in the scream equipment and the automatic power controls. The power control systems require periodic calibration, in particular because their sensitivity varies on replacement of moderators or on placing near the core of some or other bulky parts or installations used in physical experiments (cryostats, shields, test specimens, etc.) Two methods are used for absolute calibration: measurement of the amount of heat released in the stationary part of the core, and measurement

of reactor power fluctuations. Besides, during critical assemblies of the reactor the power is calibrated by the method of "source multiplication".

The first method records the expenditure and temperature drop of the air at the input and the output of both halves of the stationary core. The temperature is measured by means of thermocouples. The correction for heat release in the moving part of the core has been calculated theoretically, as well as determined experimentally from the results of the measurement of fission density distribution in the core.

The fluctuation method is the most precise and reliable. The theory developed by I.I.Bondarenko and Yu.Ya.Stavisskii (see also Ref.5 and 6) shows that relative dispersion of power released at one pulse burst is given by

$$\sigma^2 = \frac{C}{W} + \sigma_0^2 \qquad (1)$$

where W = average reactor power,

C = constant determined by physical parameters of the core,

σ_0^2 = constant component of dispersion determined by mechanical vibrations of reactor elements and by similar uncontrollable factors.

Dispersion is measured with the aid of a multichannel pulse-hight analyzer by feeding of pulses from a methane ionization chamber or a scintillation detector with an organic crystal. Experiments /2,7/ where pulse-height distributions were measured under different conditions for a number of reactor power levels confirmed expression (1). A considerable contribution to the constant dispersion component is made by fluctuations caused by the torsional oscillations of the auxiliary rotating disc. The effect of these oscillations on the pulse height spread is in an inverse dependence to the precision of phase adjustment in the rotation of the main and auxiliary discs. Pulse-height distributions are measured at three-four power levels, this enabling the constant dispersion component, σ_0^2, to be separated. All the three methods for power calibration (fluctuation, thermal and "source multiplication" produce results which agree well within the accuracy limits of each method.

The automatic control system operates on the principle of comparing the height of each reactor power pulse with the standard value.

In connection with this, at low power fluctuations impede the work of the automatic control. Automatic control is employed at power levels exceeding 50 W.

4. Reactor Operation Experience

At present the reactor operates four days each week. Two days after the shutdown the radiation level in the reactor hall decreases to such a value that most of the operations in

the hall become possible if the core is covered with the lead shield. In this case, the permissible weekly radiation dose(0.1 r.) is accumulated within 0.1-6 hrs depending on the distance from the core. The activation of the equipment parts in the hall does not cause serious difficulties. The level of activation by thermal neutrons is reduced by covering the walls, the ceiling and the floor of the hall with borax plaster and also by using no materials succeptible to strong activation in the equipment. The day preceding the routine start-up of the reactor is used for preventive maintenance of the machine bearings, the electrical motor, the startup and control equipment and other elements of the unit and for introducing the necessary alterations into the experimental physical equipment (replacement of specimens, moderators, etc.).

Until April 20, 1964 the reactor had operated at 1 kW power for 6,500 hrs and at 2.5kW for 400 hrs. During this period the reactor operation was faultless and trouble-free as far as nuclear physics is concerned. Some faults in the mechanical part of the unit, however, did occur, of which the most important ones are listed below.

(1) Breakdown of one of the journal bearings of the main disc of the reactor.The bearings were replaced with better ones, and a second, safegrounding, set of bearings was installed which would limit the skewing of the shaft if the working bearings were damaged.

(2) Breakdown of the bearing and parts of the transmission of the auxiliary disc as a result of the radiation polymerization of the bearing grase. Forced oil lubrication was introduced.

(3) Wear of the teeth of the coupling connecting the shafts of the reducing gear and of the main disc, as a result of torsional oscillations of the mechanical system. An oscillation-damping element (a coupling with rubber gaskets) was inserted between the shafts.

(4) Distortion of the coating of the main mobile uranium insert. To check the state of the insert coating , capacitive sensors were introduced which recorded the position of the coating relative to the surface of the steel disc during its rotation. By the summer of 1963 the swelling of the coating of the uranium-235 insert near the edge furthest from the rotation axis had reached 0.6 mm. At the same time , no changes were observed in the coating on the symmetrically positioned uranium-238 insert which played the role of a counterweight. At the end of 1963 the disc was renewed. In the new disc, the thickness of the insert coating was increased from 0.4 to 0.6 mm, the thickness of the insert is somewhat reduced, so that its surface is countersunk by 1 mm as related to the surface of the steel disc. The old insert has been sent for investigation to find out the causes of the surface distortion. After 400 hrs. of operation at 2.5 kW the coating of the new insert has not exhibited any perceptible distortion.

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The existing design of the reactor is inconvenient in that the replacement of the bearings or the disc requires complete disassembly of the reactor core. Since this operation needs a shutdown for 1.5-2 months for the core activity to decay, and then 2-3 weeks for core assembling, the operations to remove the faults described above in the points 1 and 4 require 4-5 months. The deficiency of radiation shielding impedes preventive maintenance of the machine. To perform thorough preventive maintenance, the machine would have to be stop - ped for about a month. The same circumstances limit the further increase in the reactor power, although it was shown by measurements of the temperatures of the core parts that the existing cooling method permits raising the power by another factor of 2 or so.

In connection with the above, a new design of the main assembly of the IBR reactor is being elaborated with a view to the maximum possible elimination of the enumerated limitations.

5. Utilization of IBR for Neutron Investigations of Liquids and Solids

At present the scattering of thermal (including cold) neutrons has become one of the principal methods for investigating the atomic and magnetic structure and dynamics of crystals, liquids and molecules. The utilization of a pulsed neutron source in such investigations greatly facilitates the staging of experiments since it disposes with a monochromator or a chopper for the incident neutron beam. True, the duration of the thermal neutron burst is found to be quite considerable-it is determined by the average neutron lifetime in the moderator, which is 200 μ sec for a "non-poisoned" thick water moderator. In view of this, the attainment of acceptable resolution requires the use of large flight distances of the order of 10 m or more, and this reduces the counting rate. In spite of this, the experiments have shown that IBR affords rather good possibilities for various solid body investigations. Below we give a brief description of installations presently used for this kind of work.

<u>5a. Neutron-Structural Investigations.</u> Fig.4 displays the arrangement of an experiment staged with the aim of ascertaining the possibilities for obtaining neutron diffraction patterns on powder specimens. In contrast to a conventional setup, in this experiment the scattering angle is fixed, and the wavelength (energy) of the neutron is variable; the time of flight serves to measure the spectrum of neutrons scattered by the specimen at a predetermined angle from an incident white spectrum. The shape of the incident spectrum is measured in a separate experiment. Fig.5 demonstrates a neutron diffraction pattern of zinc ob - tained within 11 hrs of measurements at a power of 1 kW with a specimen, 23x13 sq. cm in area, the flight distance being 15 m and the scattering angle, 60^{o} /8/. It can be seen that the comparatively high counting rate is combined with a low background. Similar measure-

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ments were conducted with silicon, aluminium and other specimens. In all cases, the relative intensities of the peaks were in good agreement with the calculations. This work was carried out jointly with the group of Prof. Buras (Warsaw) who simultaneously made an analogous experiment on a stationary reactor with a chooper [9].

The basic advantage of the time-of-flight method is that the specimen is exposed to neutrons, not continuously, but periodically for short intervals of time. This makes it possible to obtain neutron diffraction patterns of transient or short-term states of a crystal (e.g. in large pulsed magnetic fields, etc.[10]).

5b. Scattering of Cold Neutrons. The experimental layout is shown in Fig.6[11]. The specimens are placed at a distance of 60 cm from the reactor reflector after the liquid-nitrogen-cooled moderator and beryllium filter. At present, the admixture of thermal neutrons to the filtered neutrons incident upon the specimen is a few per cent. The installation enables replacement of two specimens, introduction of a cadmium filter in front of the specimen, the heating and cooling of specimens in the range from -50 to $+150^{\circ}C$. Neutrons scattered at an angle of 70° are recorded by a $B_2O_3 + ZnS$ scintillation detector with an area of 2,000 sq. cm[12]. The flight path for scattered neutrons is 10, 17 or 45 m. The resolving power during measurements over a path length of 45 m in the energy region below 0.05 ev is chiefly determined by the energy spread in the incident spectrum of beryllium-filtered neutrons, i.e. it equals $\pm$ 2 meV. In measurements using the sharp edge of the beryllium-filtered spectrum, the resolving power is $\pm 2\,\mu$sec/m, i.e. $\pm 0{,}02$ meV. The installation described served to measure cold neutron scattering spectra for water[13], ice and a number of organic compounds in the solid and liquid states. By way of example, Fig.7 contains some of the results obtained with etylene glycol.

5c. "Inverse Geometry". In measuring the hard portion of the frequency spectrum of substances, it is more advantageous to use so-called "inverse geometry" with a white neutron spectrum incident upon the specimen and the beryllium filter placed in front of the neutron detector. With such an experimental layout, cases are recorded where a neutron losss its energy to the medium; the probability of such an event is high also when the corresponding degrees of freedom at the working temperature are practically unexcited. Under our conditions, "inverse geometry" has still another advantage over "straight geometry" (discussed in the preceding section 5b) in that the test specimen is sited at a considerable distance from the reactor and is accessible to the experimenter even during reactor operation. The layout of the "inverse geometry" experiment which was conducted over a flight path of 20 m is presented in Fig.8. An example of the results obtained with NH_4Cl is given in Fig. 9.

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At the present time, this installation is employed for investigations into the movements of the group NH_4 in a number of compounds.

5d. Installation for Measuring Double Differential Scattering Cross-Sections [14]. The installation is represented schematically in Fig. 10. Its basic element is a mechanical neutron chopper rotating synchronously and in phase with the IBR disc and mounted at a distance of 10 m from it. By changing the rotation phase of the chopper it is possible to change the energy of the neutrons passing through the chopper in the from of a pulse of 50–100 μ sec duration. The spectrum formed as a result of the scattering of the monoenergetic neutron burst from the specimen is measured by the time of flight. At present, the detector is located 6 m from the specimen, and the resolution is 20 μ sec/m. It is intended to mount more than 10 detectors at different angles 10 m away from the specimen. The next task envisaged in the program consists in investigating neutron scattering from a number of hydrides and sulphur. The latter is of interest because of the large number of its allotropic modifications.

5e. Measurement of Phonon Spectra of Crystals. In the installation constructed for such investigations a monochromatic beam obtained by reflection from a large single crystal of zinc is incident upon the test specimen; the scattered spectrum is measured by the time of flight over an 8m path. Presently, the installation is being adjusted and will be used for taking the phonon spectrum of bismuth.

6. Neutron Spectrometry in the Energy Range above 1 eV

The principal objective of neutron spectrometry in the energy range above 1 ev is a study of regularities in the properties of neutron nuclear resonances. In order to obtain the most complete possible set of resonance parameters and to increase the precision of their determination, the investigations were carried out with the use of several methods. Measurements were made of total cross-sections, capture cross-sections, cross-sections of scattering and self-absorption of neutrons, fission cross-sections for fissionable nuclei, and, finally, spectra of gamma-rays arising on neutron capture in resonances.

The measurement of total cross-sections was made with a resolution of 0.04 μsec (flight path 1.000 m)7 For neutron recording use is made of a liquid scintillation detector containing methyl borate [15]. The surface area of the largest of the detectors used is 2.000 sq.cm., the efficienty for 100 ev neutrons being 50 per cent. In some measurements, a detector with scintillating lithium-containing glasses was also used. The radiative-

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capture cross-section was measured with the aid of a liquid scintillation detector[16] consisting of two 200 l tanks from which pulses may be fed to coincidence or adding circuits. The detector is installed at a distance of 750 m from the reactor, and this ensures a resolution of about 0.05 μsec/m. The neutron scattering cross-section was measured with a scintillation detector[17] containing layers of the phosphor $ZnS:B^{10}$ alterating with layers of plexiglas which served simultaneously as a moderator and a light-guide. The efficiency of the detector is about 15 per cent for 100 ev neutrons, it is nearly independent of energy. The detector is installed at a flight path of 500 m. The neutron lifetime in the detector is about 15 μ sec, depending on the thickness of the plexiglas plates.

Investigation of neutron resonances of fissionable nuclei is accomplished with the aid of a liquid detector with a capacity of about 400 l whose scintillator contains cadmium propionate (Fig. 11). Fission is recorded by delayed coincidences between the pulse associated with instantaneous gamma rays and the pulse originating on the capture of a slowed down neutron by a cadmium nucleus. The same detector serves to record radiative capture of neutrons in fissionable nuclei. By way of illustration, Fig. 12 shows fission and capture spectra for a U-235 specimen recorded with the help of this equipment. Its advantage lies in the high counting rate due to the considerable efficiency of recording fission and capture events (abt. 50 per cent) and the possibility of operating with large specimens.

Investigation of neutron resonances of non-fissionable nuclei was focused on nuclei with an odd number of protons for which a neutron capture results in the excitation of levels with two possible spin values. The availability of equipment for measuring the capture and scattering cross-sections of neutrons permitted obtaining the values of spins of levels with the aim of revealing correlations between the spin and other parameters of the levels. Also measured were the radiative widths of a number of levels for which they had not been known before. The measurements were carried out with rhodium[18] bromine[19], praseodymium and terbium[20] nuclei. About 70 resonances of these nuclei were studied, and for 30 of them the spins were determined. The use of a (n,γ)-detector made it possible to reveal a number of weak resonances, not perceptible in transmission measurements. Spectra of resonance capture gamma rays were studied for Pr[21] and Au[22]. IBR was also used for investigation of triple fission of uranium-233 and plutonium[23].

Further advances in the study of the properties of nuclear levels detectable in neutron resonances require improvements in the methods of spectrometry of resonance capture, gamma rays, a further development of methods for determining spins and parities of

levels, and, in the first place, improvement of resolution in time-of-flight measurements by an order or more.

The Neutron Physics Laboratory carries on work in all these directions. The last of these will be discussed later. As regards spin determination, the universal method is the utilization of polarized neutrons in combination with polarized nuclear targets of with a detector of scattered neutron polarization. The existing neutron polarization methods fail in the energy ragne above 10 ev. This limit may be raised to tens of KeV by polarizing neutrons, passing them through a polarized proton target [24]. Such a target has been constructed in the Laboratory [25], and experiments have been started with the aim of obtaining a polarized neutron beam. In the future measurements will be condicted with rare-earth elements in which a considerable static nuclear polarization may be obtained at $0.3^{\circ}K$.

7. Microtron and IBR Operation as a Neutron Multiplier

The disadvantage of IBR as a pulsed neutron source for spectrometry in the resonance region is the considerable duration of the burst (36 μ sec). Burst duration may be reduced drastically by using IBR under subcritical conditions as a multiplier of fast neutrons injected into the reactor by an external source. The IBR advantage as applied to such conditions is the possibility of using high factors of multiplication neutrons since during the rotation of the reactor disc for multiplication on delayed neutrons the reactor is deeply subcritical (negative reactivity-abt. 7 per cent).

The neutron injector selected for this work was an electron accelerator, microtron, designed for 30 MeV whose dimensions and weight (5t) enabled us to install it in an available room over the reactor hall. This accelerator was constructed in accordance with the design of S.P. Kapitsa and co-workers [26] and with their cooperation. Now it is in the stage of startup (Fig. 13). The installation layout may be seen in Fig. 14. The electron beam of the microtron will be focused on a uranium target placed in a channel inside the stationary part of the reactor core and will generate photoneutrons in it. The target will be cooled by a current of helium. It is easy to show that the total number of neutrons in a neutron burst of the reactor is.

$$N = \frac{S \cdot T}{|\varepsilon|}$$

where S=intensity of neutrons generated in the target,

ε=K-1-reactivity for prompt neutrons,

T-electron pulse duration.

In this case the reactor burst duration is $\theta = T + \frac{\tau}{|\varepsilon|}$

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where $\tau = 1.2 \times 10^{-8}$ sec-average lifetime of a fast neutron in the reactor.

The optimum conditions are achieved at $|\varepsilon| = \frac{\tau}{T}$; Then $\theta = 2T$ and $N = \frac{ST^2}{\tau}$

For electron beam current equal to ($S \sim 5 \times 10^{15}$ n/sec) and for $T = 1\,\mu$sec, N is abt 4×10^{11} neutrons which corresponds to a reactor power of 60 W for a repetition rate of 8.3 sec^{-1}, and 600 W for a repetition rate of 83 sec^{-1}. The efficiency of the neutron spectrometer is determined by the parameter $\frac{W}{\theta^2}$ equal to $3{,}000/36^2=2.3$ for the present operating conditions of IBR and $600/2^2=150$ for the multiplier operating conditions. Thus, operation under multiplier conditions will provide a gain of 1-2 orders of magnitude in the counting rate with equal resolution, and besides will make it possible to use a resolution higher by an order or more. The above-said refers to investigations in the epicadmium energy region. It is more advantageous to work with thermal and cold neutrons without the microtron, because the burst duration of thermal neutrons is determined by the neutron lifetime in the moderator.

Conclusions

The three years of IBR operation have shown it to be sufficiently reliable and easy to handle. At the same time, it provides considerable opportunities for neutron investigations. There are a number of ways to improve its characteristics.

Along with the authors of the present paper and of the references cited above, Ananiev V.D., Deryagin B.N., Nazarov V.M., Voronkin V.P., Rudenko V.T. took a considerable part in the utilization and improvement of IBR.

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Table 1

Data on Neutron Intensities at Average Power of 3 kW and Frequency of 3.3 1/sec.

1. Maximum power in pulse 23 Mw.
2. Average global neutron intensity 1.7×10^{14} 1/sec.
3. Global intensity in maximum of power pulse 1.3×10^{18} 1/sec.
4. Average flux of 100 ev neutrons 500 m from reactor $0.4 \frac{1}{\text{sq.cm.sec.ev}}$
5. Thermal neutron flux at 100 m from reactor $3 \times 10^{3} \frac{1}{\text{sq.cm.sec.}}$
6. Average thermal neutron flux in maximum of space distribution inside thick moderator $1.8 \times 10^{11} \frac{1}{\text{sq.cm. sec.}}$
7. Ditto in pulse maxumum $2.8 \times 10^{14} \frac{1}{\text{sq.cm.sec.}}$
8. Average fast neutron flux in core experimental channel $10^{12} \frac{1}{\text{sq.cm.sec.}}$

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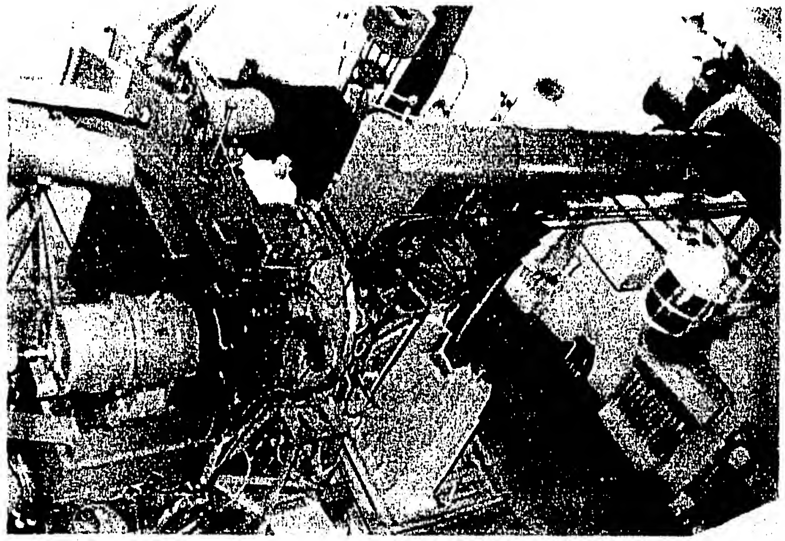

Fig 1

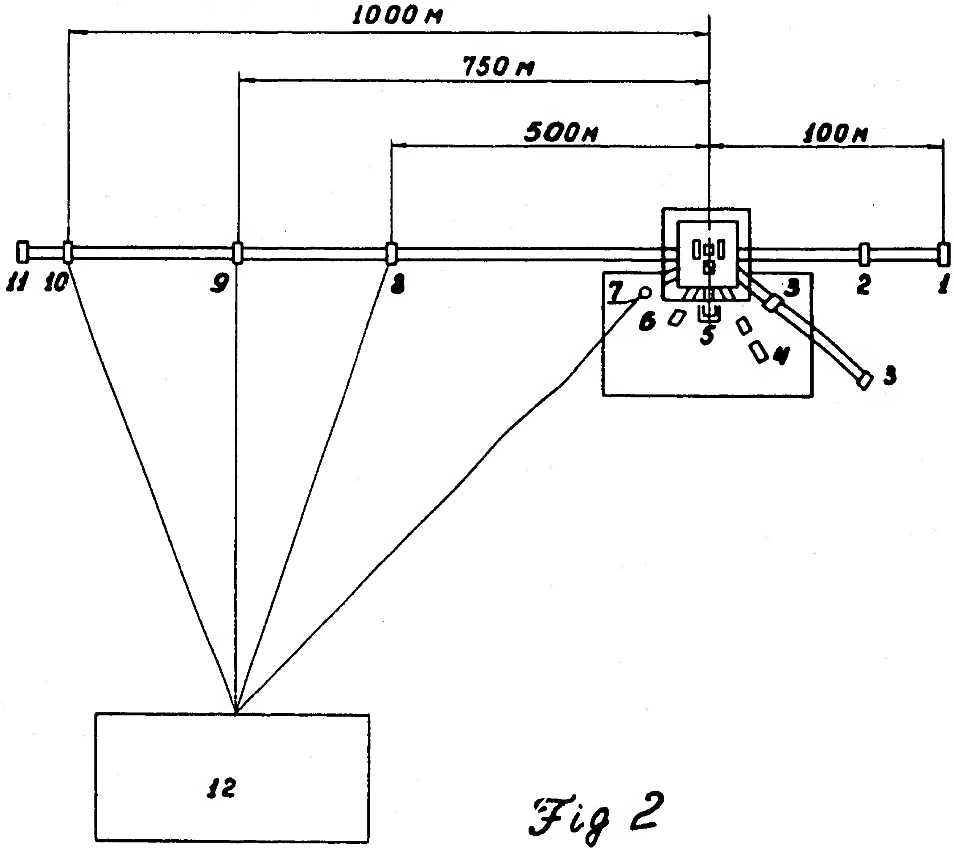

Fig 2

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Fig 3

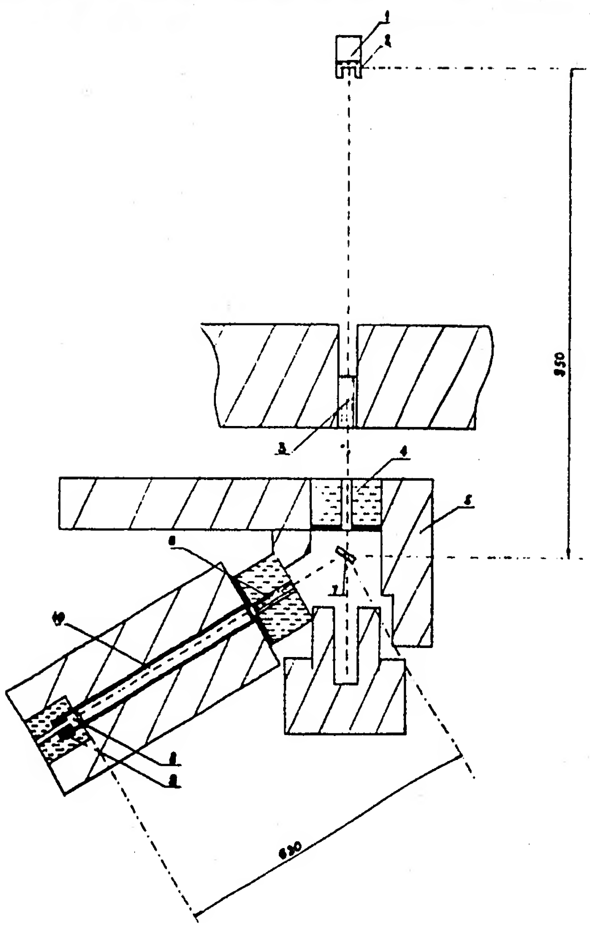

Fig 4

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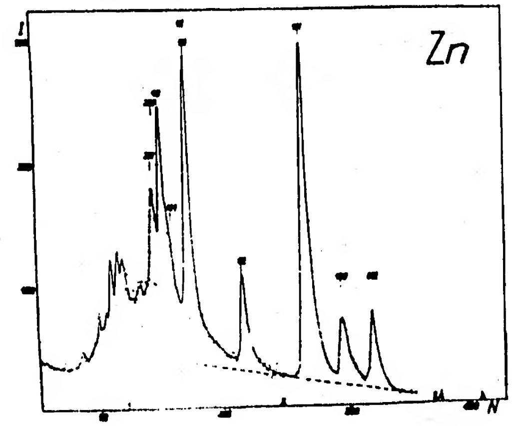

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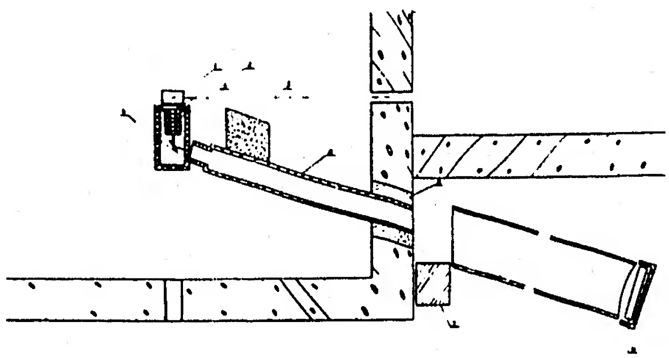

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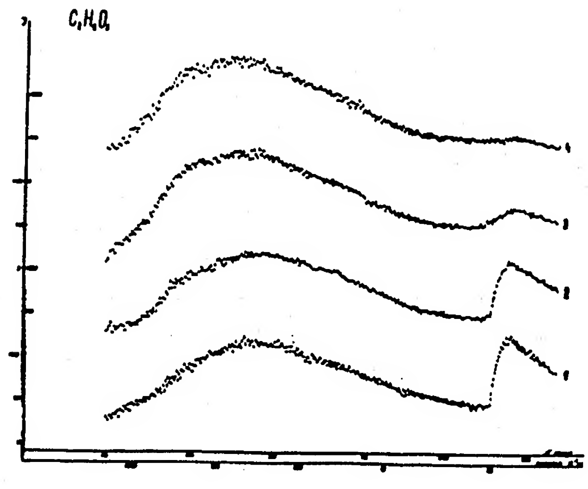

Fig 7

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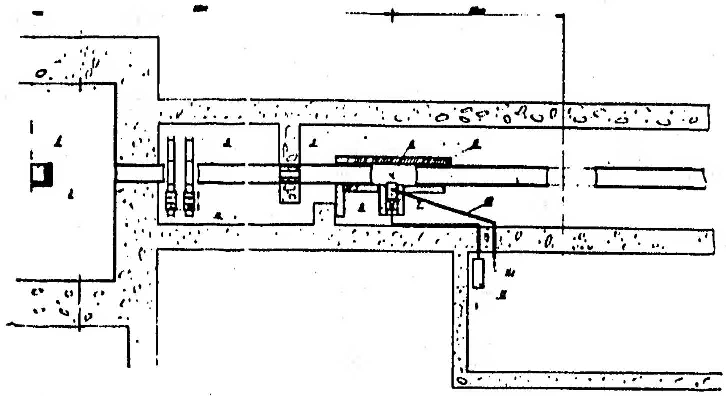

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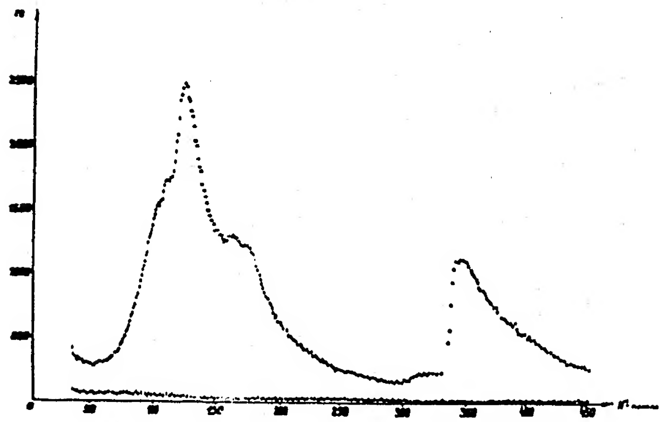

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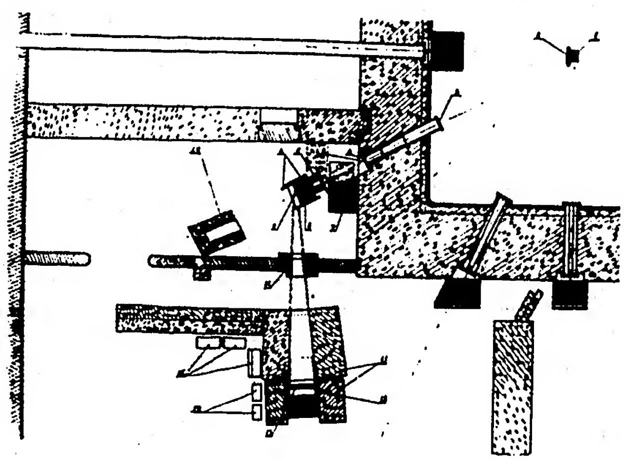

Fig 10

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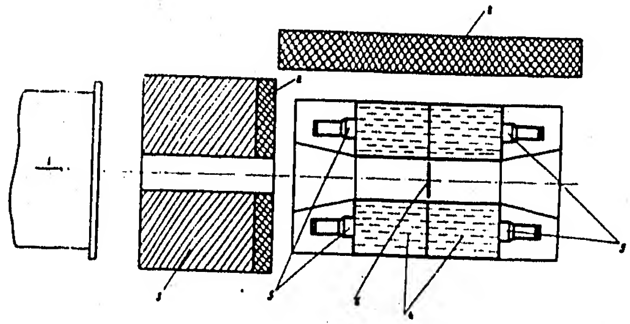

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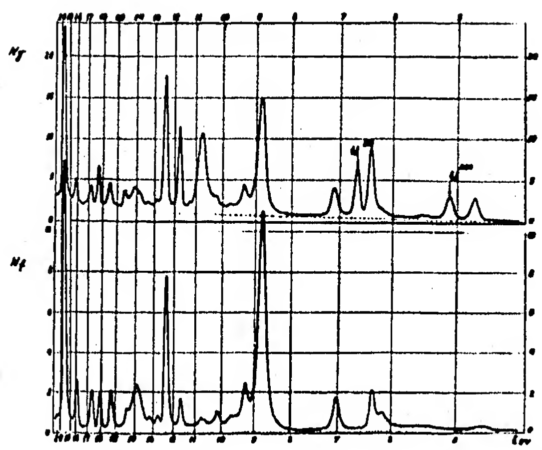

Fig 12

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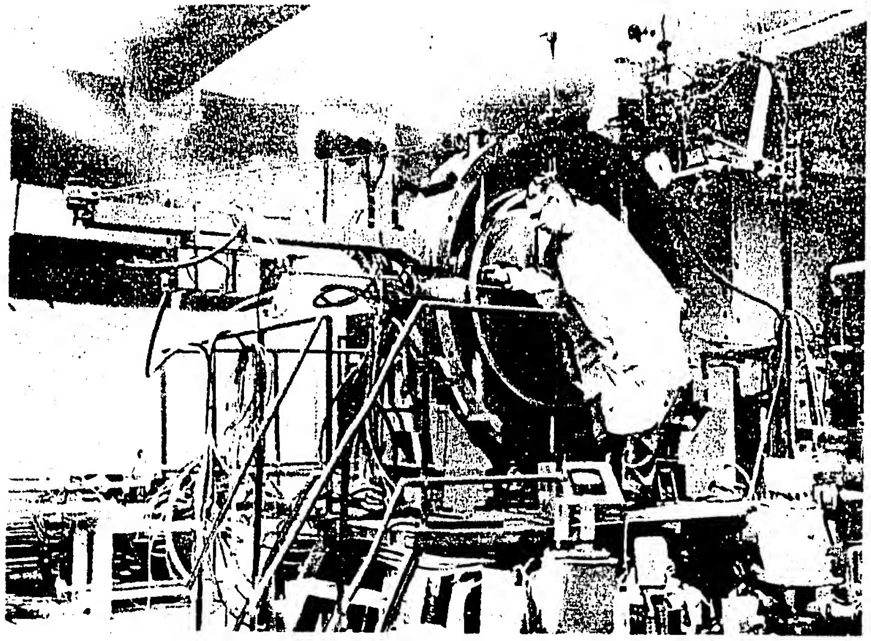

Fig 13

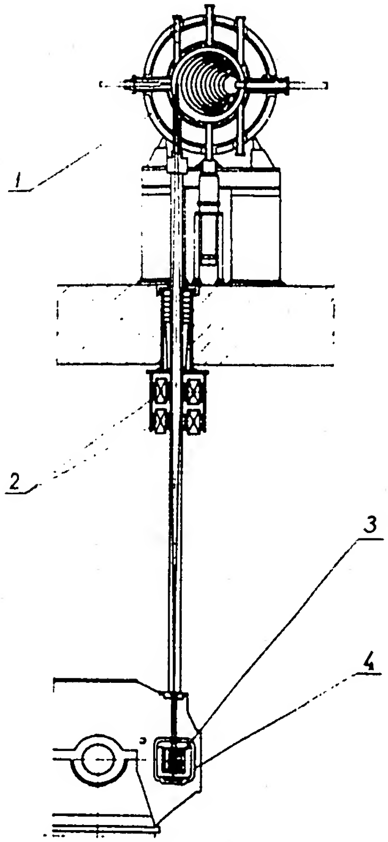

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Fig 14

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F i g. 1. General view of IBR reactor.

F i g. 2. Diagram of IBR beams. 1. Installation for investigating neutron radiative-capture gamma-rays, and scattered neutrons. 2. Installation for investigating liquids and solids by the "inverse geometry" method. 3. Installation for measurements with cold neutrons. 4. Installation for measurements with polarized neutrons. 5. Installation for measuring phonon spectra of crystals. 6. Installation for diffraction measurements. 7. Installation for measuring double differential scattering cross-sections. 8. Scattered neutron detector. 9. (n,γ) - detector. 10. Detector for transmission measurements. 11. Fission detector. 12. Measuring centre.

F i g. 3. Laboratory measuring centre.

F i g. 4. Diagram of installation for neutron diffraction studies. 1. IBR core. 2. Moderator. 3,6. Collimators. 4. Water shield. 5. Concrete shield. 7. Specimen. 8. Detector of zinc sulphide with boron-10. Neutron guide.

F i g. 5. Neutron diffraction pattern of zinc.

F i g. 6. Diagram of installation for measuriments with cold neutrons. 1. IBR core. 2. Moderator. 3. Beryllium filter. 4. Specimen. 5,6,8. Shield. 7. Slide gate. 9. Detector.

F i g. 7. Spectra of neutrons scattered from ethylene glycol at temperatures of: $-18^{\circ}C(1)$, $+10^{\circ}C(2)$, $+90^{\circ}C(3)$, $+150^{\circ}C(4)$.

F i g. 8. Diagram of installation for investigating liquids and solids by "inverse geometry" method. 1. Reactor. 2. Moderator. 3. Vacuum neutron guide. 4,5. Collimators. 6. Specimen. 7. Beryllium filter. 8. Neutron detector ZnS+B. 9. Shield. 10. Filling with liquid nitrogen. 11. Detector electronics.

F i g. 9. Spectrum of neutrons scattered from NH_4Cl. Measurement time 1 hr at 1 kW. Scattering angle, 90°. Channel width 64 μ sec. Specimen transmission 83 per cent for energy of 5 mev.

F i g. 10. Diagram of installation for measuring double differential cross-sections of scattered neutrons. 1. IBR reactor. 2. Moderator. 3. Aluminium dampers. 4. Neutron quide. 5. Collimator. 6. Paraffine-boron shield. 7. Slide gate. 8. Chopper. 9. Specimen. 10. Neutron trap. 11. Concrete shield. 12. Detector shield. 13. Detector. 14. Electronic equipment. 15. Electronic equipment of phasing system.

F i g. 11. Diagram of detector for fission recording. 1. Neutron beam. 2. Lead. 3. Paraffine and boron. 4. Liquid scintillator. 5. Photomultipliers. 6. Test specimen.

F i g. 12. Experimental curves of resonance capture (above) and fission (below) for uranium-235. Instrument peak is denoted by dashed line.

F i g. 13. Microtron. Accelerator chamber is open.

F i g. 14. Layout of microtron and IBR reactor. 1. Accelerator chamber. 2. Focusing lenses. 3. Target. 4. Reactor core.

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